

WEAK DECAYS, CKM AND CP VIOLATION

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Abstract

I review several topics pertaining to Weak decays of b and c quarks, including measurements of $|V_{cb}|$, $|V_{ub}/V_{cb}|$, f_{D_s} and $b \rightarrow s\gamma$.

1 Introduction

Leptons and quarks, along with gluons, photons and gauge bosons are the fundamental objects in nature described by the Standard Model of electroweak interactions. Although the model has been successful at describing the interactions between these objects, many important questions remain.

- Why are there so many fundamental constants?
- What is the relationship of these constants to quark masses?
- Are quarks and leptons really pointlike?
- Is the Standard Model description correct, especially of CP violation?
- What is the connection between CP and matter-antimatter asymmetry?

In weak interactions of quarks, we are interested in the couplings of quarks to each other and leptons, but have to deal with the “brown muck” of hadrons. The basic weak $V - A$ structure has been verified with purely leptonic decays, for example, $\mu \rightarrow e\nu_e\nu_\mu$, $\tau \rightarrow e\nu_e\nu_\tau$. I do not have enough space to report on all interesting aspects of weak decays here, so I will report on a few, but miss others, even ones which I covered in my presentation.

1.1 The CKM Matrix and CP Violation

The physical point-like states of nature that have both strong and electroweak interactions, the quarks, are mixtures of base states described by the Cabibbo-Kobayashi-Maskawa matrix,¹

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

The unprimed states are the mass eigenstates, while the primed states denote the weak eigenstates. There are nine complex CKM elements. These 18

numbers can be reduced to four independent quantities by applying unitarity and the fact that the phases of the quark wave functions are arbitrary. These four remaining numbers are fundamental constants of nature that need to be determined from experiment, like any other fundamental constant such as α or G . In the Wolfenstein approximation the matrix is written as²

$$V_{CKM} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta(1 - \lambda^2/2)) \\ -\lambda & 1 - \lambda^2/2 - i\eta A^2\lambda^4 & A\lambda^2(1 + i\eta\lambda^2) \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}.$$

This expression is accurate to order λ^3 in the real part and λ^5 in the imaginary part. It is necessary to express the matrix to this order to have a complete formulation of the physics we wish to pursue. The constants λ and A have been measured using semileptonic s and b decays;³ $\lambda \approx 0.22$, and $A \approx 0.8$.

The phase η allows for CP violation. CP violation thus far has only been seen in the neutral kaon system. If we can find CP violation in the B system we could see if the CKM model works or perhaps discover new physics that goes beyond the model, if it does not.

It is also of great interest to measure the magnitudes of each of the matrix elements. Techniques used have included: V_{ud} from $0^+ \rightarrow 0^+$ nuclear β -decay, V_{us} from $K \rightarrow \pi\ell\nu$ and hyperon semileptonic decays, V_{ub} from charmless semileptonic b decays, V_{cd} from neutrino interactions and charm semileptonic decay, V_{cs} from direct W^\pm decays at LEP II, V_{cb} from charmed semileptonic b decays, V_{td} from B_d^0 mixing, limits on V_{ts} from B_s mixing, and limits on V_{tb} from t decays. The measurements of V_{cb} and V_{ub} will be discussed here.

1.2 Measurement Of $|V_{cb}|$ Using $B \rightarrow D^*\ell\nu$

Currently, the most favored technique is to measure the decay rate of $B \rightarrow D^*\ell^-\bar{\nu}$ at the kinematic point where the D^{*+} is at rest in the B rest frame (this is often referred to as maximum q^2 or $\omega = 1$). Here, according to Heavy Quark Effective Theory, the theoretical uncertainties are at a minimum.

There are results from several groups using this technique for the decay sequence $D^{*+} \rightarrow \pi^+ D^0$; $D^0 \rightarrow K^-\pi^+$, or similar decays of the D^{*0} . The ALEPH results⁴ are shown in Fig. 1.

In a recent analysis, DELPHI detects only the slow π^+ from the D^{*+} decay and does not explicitly reconstruct the D^0 decay.⁵ Table 1 summarizes determinations of $|V_{cb}|$; here, the first error is statistical, the second systematic and the third, an estimate of the theoretical accuracy in predicting the form-factor $F(\omega = 1) = 0.91 \pm 0.003$.⁸ Currently, DELPHI has the smallest error, however, CLEO has only used 1/6 of their current data. The quoted average

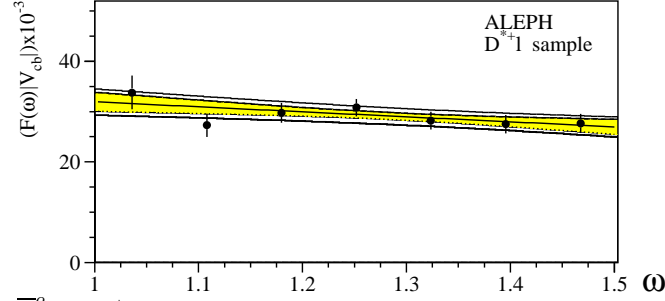


Figure 1. $\bar{B}^0 \rightarrow D^+ \ell^- \bar{\nu}$ from ALEPH. The data have been fit to a functional form suggested by Caprini *et al.* The abscissa gives the value of the product $|F(1) * V_{cb}|^2$.

$|V_{cb}| = 0.0381 \pm 0.0021$ combines the averaged statistical and systematic errors with the theoretical error in quadrature and takes into account the common systematic errors, such as the D^* branching ratios.

Table 1. Modern Determinations of $|V_{cb}|$ using $B \rightarrow D^* \ell^- \bar{\nu}$ decays at $\omega = 1$

Experiment	$V_{cb} (\times 10^{-3})$
ALEPH ⁴	$34.4 \pm 1.6 \pm 2.3 \pm 1.4$
DELPHI ⁵	$41.2 \pm 1.5 \pm 1.8 \pm 1.4$
OPAL ⁶	$36.0 \pm 2.1 \pm 2.1 \pm 1.2$
CLEO ⁷	$39.4 \pm 2.1 \pm 2.0 \pm 1.4$
Average	38.1 ± 2.1

There are other ways of determining V_{cb} . One new method based on QCD sum rules uses the operator product expansion and the heavy quark expansion, in terms of the parameters $\alpha_s(m_b)$, $\bar{\Lambda}$, and the matrix elements λ_1 and λ_2 . The latter quantities arise from the differences

$$m_B - m_b = \bar{\Lambda} - \frac{\lambda_1 + 3\lambda_2}{2m_b} \quad m_B^* - m_b = \bar{\Lambda} - \frac{\lambda_1 + \lambda_2}{2m_b} \quad .$$

The $B^* - B$ mass difference determines $\lambda_2 = 0.12 \text{ GeV}^2$. The total semileptonic decay width is then related to above parameters as

$$\Gamma_{sl} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} 0.369 \times$$

$$\left[1 - 1.54 \frac{\alpha_s}{\pi} - 1.65 \frac{\bar{\Lambda}}{m_B} \left(1 - .087 \frac{\alpha_s}{\pi} \right) - 0.95 \frac{\bar{\Lambda}^2}{m_B^2} - 3.18 \frac{\lambda_1}{m_B^2} + 0.02 \frac{\lambda_2}{m_B^2} \right]$$

CLEO has measured the semileptonic branching ratio using lepton tags as $(10.49 \pm 0.17 \pm 0.43)\%$ and using the world average lifetime for an equal mixture of B^0 and B^- mesons of 1.613 ± 0.020 ps, CLEO finds $\Gamma_{sl} = 65.0 \pm 3.0 \text{ ns}^{-1}$. (Note that LEP has a somewhat larger value of $68.6 \pm 1.6 \text{ ns}^{-1}$.)

CLEO then attempts to measure the remaining unknown parameters λ_1 and $\bar{\Lambda}$ by using moments of either the hadronic mass or the lepton energy.⁹ The results are shown in Fig. 2. Here the measurements are shown as bands reflecting the experimental errors. Unfortunately, this preliminary CLEO result shows a contradiction. The overlap of the mass moment bands gives different values than the lepton energy moments! The mass moments are theoretically favored and give the values $\lambda_1 = (0.13 \pm 0.01 \pm 0.06) \text{ GeV}^2$, and $\bar{\Lambda} = (0.33 \pm 0.02 \pm 0.08) \text{ GeV}$. The discrepancy between the two methods is serious. It either means that there is something wrong with the CLEO analysis or there is something wrong in the theory. If the latter is true it would shed doubt on the method used by the LEP experiments to extract a value of $|V_{ub}|$ using the same theoretical framework.

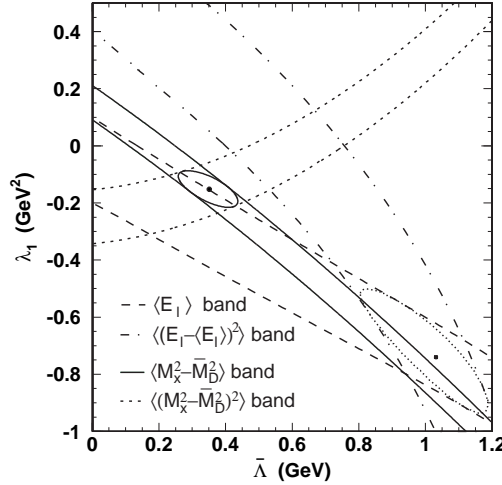


Figure 2. Bands in $\bar{\Lambda} - \lambda_1$ space found by CLEO in analyzing first and second moments of hadronic mass squared and lepton energy. The intersections of the two moments for each set determines the two parameters. The one standard deviation error ellipses are shown.

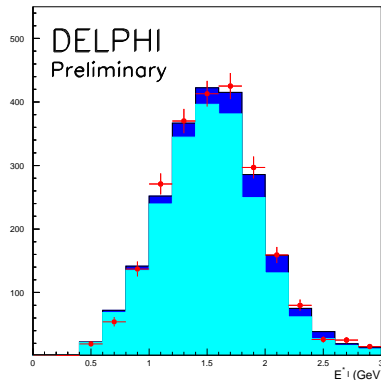


Figure 3. The lepton energy distribution in the B rest frame from DELPHI. The data have been enriched in $b \rightarrow u$ events, and the mass of the recoiling hadronic system is required to be below 1.6 GeV. The points indicate data, the light shaded region, the fitted background and the dark shaded region, the fitted $b \rightarrow u\ell\nu$ signal.

1.3 Measurement Of $|V_{ub}|$

Another important CKM element that can be measured using semileptonic decays is V_{ub} . The first measurement of V_{ub} done by CLEO and subsequently confirmed by ARGUS, used only leptons which were more energetic than those that could come from $b \rightarrow c\ell^-\bar{\nu}$ decays.¹⁰ These “endpoint leptons” can occur, $b \rightarrow c$ background free, at the $\Upsilon(4S)$ because the B ’s are almost at rest. Unfortunately, there is only a small fraction of the $b \rightarrow u\ell^-\bar{\nu}$ lepton spectrum that can be seen this way, leading to model dependent errors.

ALEPH¹¹ L3¹² and DELPHI¹³ try to isolate a class of events where the hadron system associated with the lepton is enriched in $b \rightarrow u$ and thus depleted in $b \rightarrow c$. They define a likelihood that hadron tracks come from b decay by using a large number of variables including, vertex information, transverse momentum, not being a kaon. Then they require the hadronic mass to be less than 1.6 GeV, which greatly reduces $b \rightarrow c$, since a completely reconstructed $b \rightarrow c$ decay has a mass greater than that of the D (1.83 GeV). They then examine the lepton energy distribution for this set of events, shown in Fig. 3 for DELPHI.

I have averaged all three LEP results and show them in Fig. 4 without any theoretical error, which is estimated at $\pm 8\%$ by Uraltsev.¹⁴ However, another calculation using the same type of model by Jin¹⁵ gives a $\pm 14\%$ lower value, with a quoted error of $\pm 10\%$.

My best estimate of $|V_{ub}/V_{cb}|$ using this technique includes a $\pm 14\%$ the-

oretical error added in quadrature with a common systematic error of $\pm 14\%$, since the Monte Carlo calculations at LEP are known to be strongly correlated.

Also shown in Fig. 4 are results from CLEO using the measured the decay rates for the exclusive final states $\pi\ell\nu$ and $\rho\ell\nu$,¹⁸ and results from endpoint leptons, dominated by CLEO II.¹⁷ Several theoretical models are used.¹⁶ From the exclusive results, the model of Korner and Schuler (KS) is ruled out by the measured ratio of ρ/π . This model deviated the most from the others used to get values of $|V_{ub}|$ from endpoint leptons. Thus the main use of the exclusive final states has been to restrict the models. The endpoint lepton results are statistically the most precise. Assigning a model dependent error is quite difficult. I somewhat arbitrarily have assigned a $\pm 14\%$ irreducible systematic error to these models and used the average among them to derive a value. My best overall estimate is that $|V_{ub}/V_{cb}| = 0.087 \pm 0.012$.

This estimate must be treated as highly suspect. The value and error depends on uncertain theoretical estimates. We can use this estimate, along with other measurements. To get some idea of what the values of ρ and η are.

There is a constraint on ρ and η given by the K_L^0 CP violation measurement (ϵ), given by¹⁹

$$\eta [(1 - \rho)A^2(1.4 \pm 0.2) + 0.35] A^2 \frac{B_K}{0.75} = (0.30 \pm 0.06),$$

where the errors arise mostly from uncertainties on $|V_{cb}|$ and B_K . Here B_K is taken as 0.75 ± 0.15 according to Buras.²⁰ The constraints on ρ versus η from the $|V_{ub}/V_{cb}|$ determination, ϵ and B mixing are shown in Fig. 5. The bands represent $\pm 1\sigma$ errors, for the measurements and a 95% confidence level upper limit on B_s mixing. The width of the B_d mixing band is caused mainly by the uncertainty on f_B , taken here as $240 > f_B > 160$ MeV. Other parameters include $|V_{cb}| = 0.381 \pm 0.0021$, $|V_{ub}/V_{cb}| = 0.087 \pm 0.012$, limit on $\Delta M_s > 12.4$ ps⁻¹, and the ratio $f_{B_s}\sqrt{B_{B_s}}/f_{B_d}\sqrt{B_{B_d}} \leq 1.25$.²¹

2 The decays $B^- \rightarrow \ell^- \bar{\nu}$ and $D_s^+ \rightarrow \mu^+ \nu$

This reaction proceeds via the annihilation of the b quark with the \bar{u} into a virtual W^- which materializes as $\ell^- \bar{\nu}$ pair as illustrated in Fig. 6. The decay rate for this process can be written as

$$\Gamma(B^- \rightarrow \ell^- \bar{\nu}) = \frac{G_F^2}{8\pi} f_B^2 m_\ell^2 M_B \left(1 - \frac{m_\ell^2}{M_B^2}\right)^2 |V_{ub}|^2, \quad ,$$

where f_B is the so called “decay constant,” a parameter that can be calculated theoretically or determined by measuring the decay rate. This formula is the

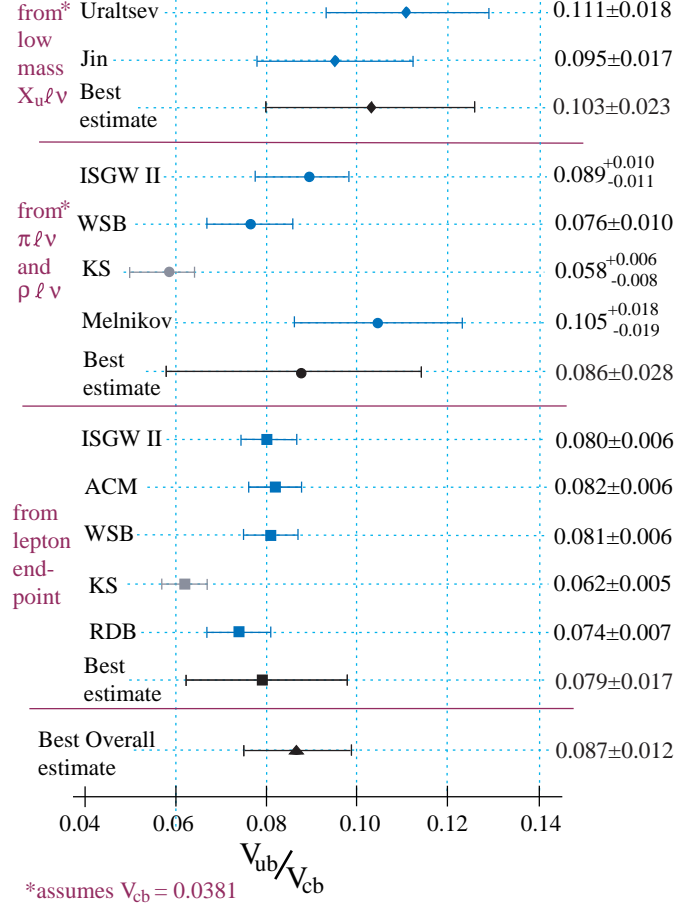


Figure 4. Measurements of $|V_{ub}/V_{cb}|$ using different techniques and theoretical models. (The KS model has been ruled out.)

same for all pseudoscalar mesons using the appropriate CKM matrix element and decay constant.

Knowledge of f_B is important because it is used to determine constraints on CKM matrix elements from measurements of neutral B mixing. Since the decay is helicity suppressed, the heavier the lepton the larger the expected

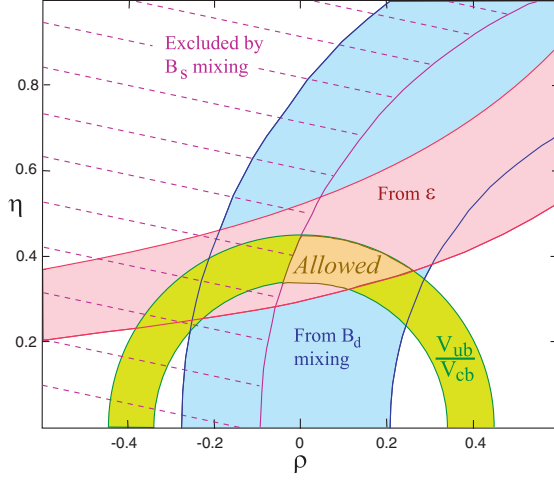


Figure 5. The regions in ρ - η space (shaded) consistent with measurements of CP violation in K_L^0 decay (ϵ), V_{ub}/V_{cb} in semileptonic B decay, B_d^0 mixing, and the excluded region from limits on B_s^0 mixing. The allowed region is defined by the overlap of the 3 permitted areas, and is where the apex of the CKM triangle sits.

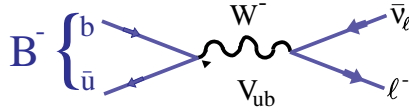


Figure 6. Diagram for a $B^- \rightarrow \ell^- \bar{\nu}$ decay.

rate. Thus looking for the $\tau^- \bar{\nu}$ has its advantages. The big disadvantage is that there are least two missing neutrinos in the final state. The most stringent limit has been set by L3 of $< 5.7 \times 10^{-4}$ at 90% confidence level, using a missing energy technique.²² This is still one order of magnitude higher than what is expected. Other limits are poorer.²³

Since f_B is so difficult to measure, models, especially lattice gauge models, are used.²⁵ However, it is prudent to test these models. $D_s^+ \rightarrow \mu^+ \nu$ can be used; it is Cabibbo favored and the predicted branching ratio is close to 1%.

CLEO has made the highest statistics measurement to date of $\mathcal{B}(D_s^+ \rightarrow \mu^+ \nu)$, by searching for the decay sequence $D_s^{*+} \rightarrow \gamma D_s^+$, $D_s^+ \rightarrow \mu^+ \nu$. Since the decay $D_s \rightarrow e \nu$ is suppressed by four orders of magnitude due to helicity, they use this mode to measure the physics backgrounds due to real muons. Then they need correct only for differences in muon and electron efficiencies and fake rates. They use missing energy and momentum to define the ν

direction. The mass difference ΔM is calculated as difference in D_s^* and D_s invariant mass. The ΔM distributions for the muon and electron data and the calculated effective excess of muon fakes over electron fakes are shown in Fig. 7(a). The histogram is the result of a χ^2 fit of the muon spectrum to the sum of three contributions: the signal, the scaled electrons, and the excess of muon over electron fakes. Here, the sizes of the electron and fake contributions are fixed and only the signal normalization is allowed to vary. The signal consists of two components, whose relative normalization is fixed. These two components are the decay $D_s^{*+} \rightarrow \gamma D_s^+$, $D_s^+ \rightarrow \mu^+ \nu$ and the direct decay $D_s^+ \rightarrow \mu \nu$ and $D^+ \rightarrow \mu^+ \nu$ combined with a random photon.

CLEO finds a signal of 182 ± 22 events in the peak which are attributed to the process $D_s^{*+} \rightarrow \gamma D_s^+$, $D_s^+ \rightarrow \mu^+ \nu$. They also find 250 ± 38 events in the flat part of the distribution corresponding to $D_s^+ \rightarrow \mu^+ \nu$ or $D^+ \rightarrow \mu^+ \nu$ decays coupled with a random photon. The contribution of a real $D^+ \rightarrow \mu^+ \nu$ decay with random photons is not entirely negligible since the $D^{*+} \rightarrow \gamma D^+$ branching ratio does not enter. The D^+ fraction is estimated to be about $(18 \pm 8)\%$ relative to the total $D_s^+ \rightarrow \mu^+ \nu$ plus random photon contribution.

Several other groups have made measurements. The results are shown in Table 2. I have changed the values of f_{D_s} according to the updated PDG D_s decay branching fractions for the normalization modes,²⁴ and have corrected the old CLEO result by using the new fake rates determined in their updated analysis. In addition, there are new results using the $D_s^+ \rightarrow \tau^+ \nu$ decay

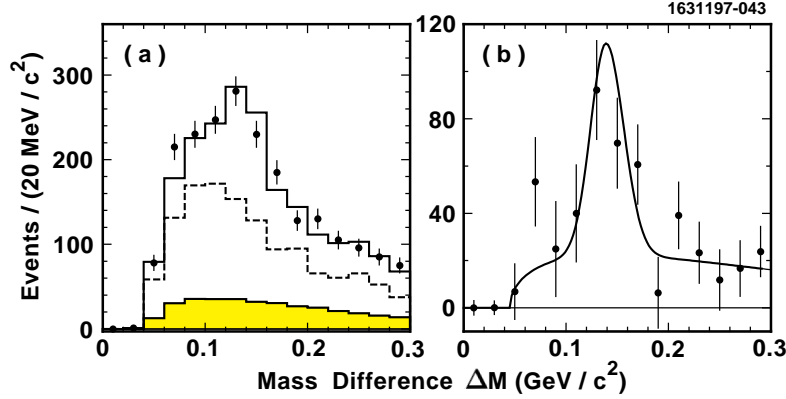


Figure 7. (a) The ΔM mass difference distribution for D_s^{*+} candidates for both the muon data (solid points), the electron data (dashed histogram) and the excess of muon fakes over electron fakes (shaded). The histogram is the result of the fit described in the text. (b) The ΔM mass difference distribution for D_s^{*+} candidates with electrons and excess muon fakes subtracted. The curve is a fit to the signal shape described in the text.

from the L3 collaboration²² of $(309 \pm 58 \pm 33 \pm 38)$ MeV, and (330 ± 95) MeV from the DELPHI collaboration.²³ The world average value for f_{D_s} is $(255 \pm 21 \pm 28)$ MeV, where the common systematic error is due the error on the absolute branching ratio for $D_s^+ \rightarrow \phi\pi^+$. These numbers are consistent with C. Bernard’s world average for lattice theories of (221 ± 25) MeV.²⁵

Table 2. Measured values of f_{D_s} from experimental values of $\Gamma(D_s^+ \rightarrow \mu^+\nu)$

Collaboration	Observed Events	Published f_{D_s} value (MeV)	Corrected f_{D_s} value (MeV)
CLEO (old) ²⁶	39 \pm 8	344 \pm 37 \pm 52 \pm 42	282 \pm 30 \pm 43 \pm 34
WA75 ²⁷	6	232 \pm 45 \pm 20 \pm 48	213 \pm 41 \pm 18 \pm 26
BES ²⁸	3	430 ⁺¹⁵⁰ ₋₁₃₀ \pm 40	Same
E653 ²⁹	23.2 \pm 6.0 ^{+1.0} _{-0.9}	194 \pm 35 \pm 20 \pm 14	200 \pm 35 \pm 20 \pm 26
CLEO ³⁰	182 \pm 22	-	280 \pm 19 \pm 28 \pm 34

3 Rare Decays as Probes beyond the Standard Model

Rare decays have loops in the decay diagrams so they are sensitive to high mass gauge bosons and fermions. Thus, they are sensitive to new physics. However, it must be kept in mind that any new effect must be consistent with already measured phenomena such as B_d^0 mixing and $b \rightarrow s\gamma$.

These processes are often called “Penguin” processes, for unscientific reasons. A Feynman loop diagram is shown in Fig. 8 that describes the transition of a b quark into a charged $-1/3$ s or d quark, which is effectively a neutral current transition. The dominant charged current decays change the b quark into a charged $+2/3$ quark, either c or u .

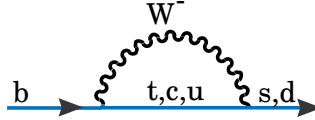


Figure 8. Loop or “Penguin” diagram for a $b \rightarrow s$ or $b \rightarrow d$ transition.

The intermediate quark inside the loop can be any charge $+2/3$ quark. The relative size of the different contributions arises from different quark masses and CKM elements. In terms of the Cabibbo angle ($\lambda=0.22$), we have for $t:c:u$ - $\lambda^2:\lambda^2:\lambda^4$. The mass dependence favors the t loop, but the amplitude for c processes can be quite large $\approx 30\%$. Moreover, as pointed out by Bander, Silverman and Soni,³¹ interference can occur between t , c and u diagrams and

lead to CP violation. In the standard model it is not expected to occur when $b \rightarrow s$, due to the lack of a CKM phase difference, but could occur when $b \rightarrow d$. In any case, it is always worth looking for this effect; all that needs to be done, for example, is to compare the number of $K^{*-}\gamma$ events with the number of $K^{*+}\gamma$ events.

There are other possibilities for physics beyond the standard model to appear. For example, the W^- in the loop can be replaced by some other charged object such as a Higgs; it is also possible for a new object to replace the t .

3.1 $b \rightarrow s\gamma$

This process occurs when any of the charged particles in Fig. 8 emits a photon. CLEO first measured the inclusive rate³² as well as the exclusive rate into $K^*(890)\gamma$.³³ There is an updated CLEO measurement³⁴ using 1.5 times the original data sample and a new measurement from ALEPH.³⁵

To remove background CLEO used two techniques originally, one based on “event shapes” and the other on summing exclusively reconstructed B samples. CLEO uses eight different shape variables,³² and defines a variable r using a neural network to distinguish signal from background. The idea of the B reconstruction analysis is to find the inclusive branching ratio by summing over exclusive modes. The allowed hadronic system is comprised of either a $K_s \rightarrow \pi^+\pi^-$ candidate or a K^\mp combined with 1-4 pions, only one of which can be neutral. The restriction on the number and kind of pions maximizes efficiency while minimizing background. It does however lead to a model dependent error. Then both analysis techniques are combined. Currently, most of the statistical power of the analysis ($\sim 80\%$) comes from summing over the exclusive modes.

Fig. 9 shows the photon energy spectrum of the inclusive signal, compared with the model of Ali and Greub.³⁶ A fit to the model over the photon energy range from 2.1 to 2.7 GeV/c gives the branching ratio result shown in Table 3, where the first error is statistical and the second systematic.

Table 3. Experimental results for $b \rightarrow s\gamma$

Sample	branching ratio
CLEO	$(3.15 \pm 0.35 \pm 0.41) \times 10^{-4}$
ALEPH	$(3.11 \pm 0.80 \pm 0.72) \times 10^{-4}$
Average	$(3.14 \pm 0.48) \times 10^{-4}$
Theory ³⁷	$(3.28 \pm 0.30) \times 10^{-4}$

ALEPH reduces the backgrounds by weighting candidate decay tracks

in a $b \rightarrow s\gamma$ event by a combination of their momentum, impact parameter with respect to the main vertex and rapidity with respect to the b -hadron direction.³⁵ Their result is shown in Table 3. The world average value experimental value is also given, as well as the theoretical prediction.

The consistency with standard model expectation has ruled out many models. Hewett has given a good review of the many minimal supergravity models which are excluded by the data.³⁸

Triple gauge boson couplings are of great interest in checking the standard model. If there were an anomalous $WW\gamma$ coupling it would serve to change the standard model rate. $p\bar{p}$ collider experiments have also published results limiting such couplings.³⁹ In a two-dimensional space defined by $\Delta\kappa$ and λ , the D0 constraint appears as a tilted ellipse and the $b \rightarrow s\gamma$ as nearly vertical bands. In the standard model both parameters are zero.

Acknowledgments

I thank Marina Artuso, B. Kayser, R. Peccei, Jon Rosner, and Tomasz Skwarnicki for interesting discussions. This work was supported by the U. S. National Science Foundation.

References

1. N. Cabibbo, *Phys. Rev. Lett.* **10**, 531 (1963); M. Kobayashi and K. Maskawa, *Prog. Theor. Phys.* **49**, 652 (1973).
2. L. Wolfenstein, *Phys. Rev. Lett.* **51**, 1945 (1983).
3. S. Stone, "Prospects For B-Physics In The Next Decade," in *Techniques*

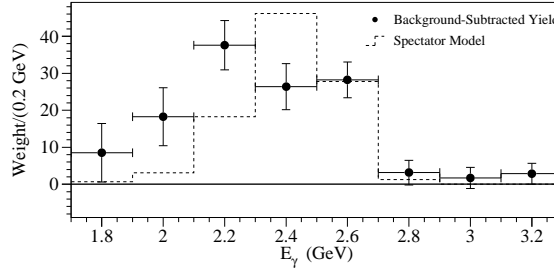


Figure 9. The background subtracted photon energy spectrum from CLEO. The dashed curve is a spectator model prediction from Ali and Greub.

- and *Concepts of High-Energy Physics IX*, ed. by T. Ferbel, NATO ASI Series, Plenum, NY (1996).
4. D. Buskulic *et al.* (ALEPH), *Phys. Lett. B* **395** (1997) 373.
 5. M. Margoni *et al.*, (DELPHI), *Measurement of V_{cb} Using the Identified Charged Pion in $\overline{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}$* , DELPHI 98-140, (1998).
 6. K. Ackerstaff *et al.* (OPAL), *Phys. Lett. B* **395** (1997) 128.
 7. B. Barish *et al.* (CLEO), *Phys. Rev. D* **51** 1014 (1995). The CLEO value has been boosted by 2.6% to account for the expected negative curvature near $\omega = 1$, see S. Stone, *Probing the CKM Matrix with b Decays* in Proc. of *The Albuquerque Meeting*, ed. S. Seidel, World Scientific, Singapore 871 (1994).
 8. I. Caprini and M. Neubert, *Phys. Lett. B* **380** 376 (1996); M. Shifman *et al.*, *Phys. Rev. D* **51** 2217 (1995); Erratum-ibid. D52 3149 (1995); A. Czarnecki, *Phys. Rev. Lett.* **76** 4124 (1996); T. Mannel, *Phys. Rev. D* **50** 428 (1994); A. F. Falk and M. Neubert, *Phys. Rev. D* **47** 2965 and 2982 (1993).
 9. J. Bartelt *et al.*, “Moment Analysis of Inclusive Semileptonic B Meson Decay,” submitted to XXIX Int. Conf. on High Energy Physics, Vancouver, Canada (1998) (ICHEP98-1013).
 10. R. Fulton *et al.* (CLEO), *Phys. Rev. Lett.* **16** 64 (1990); H. Albrecht *et al.* (ARGUS), *Phys. Lett. B* **234** 409 (1990).
 11. R. Barate *et al.* (ALEPH), *Eur. Phys. J. C* **6** 555 (1999).
 12. M. Acciarri *et al.* (L3), *Phys. Lett., B* **436** 174 (1998).
 13. M. Battaglia *et al.* (DELPHI), *Measurement of $|V_{ub}|/|V_{cb}|$ with DELPHI at LEP*, DELPHI 98-97 CONF 165 submitted to the XXIX Int. Conf. on High Energy Physics, Vancouver, #241 (1998).
 14. N. G. Uraltsev, *Int. J. Mod. Phys. A* **11** 515 (1996); I. Bigi *et al.*, *Annu. Rev. Nucl. Part. Sci.*, **47** 591 (1997).
 15. C. Jin, hep-ph/9810427 (1998).
 16. N. Isgur and D. Scora (ISGW II), *Phys. Rev. D* **52**, 2783 (1995); N. Isgur, D. Scora, B. Grinstein, and M. B. Wise, *Phys. Rev. D* **39**, 799 (1989); M. Wirbel, B. Stech and M. Bauer *Z. Phys. C* **29**, 637 (1985); M. Bauer and M. Wirbel (WBS), *Z. Phys. C* **42** 671 (1989); J. G. Korner and G. A. Schuler (KS), *Z. Phys. C* **38** 511 (1988); *ibid.* (erratum) *C* **41** 690 (1989); D. Melikhov, *Phys. Rev. D* **53** 2460 (1996); G. Altarelli *et al.* (ACM), *Nucl. Phys. B* **208** 365 (1982); C. Ramirez, J. F. Donoghue and G. Burdman (RDB), *Phys. Rev. D* **41** 1496 (1990).
 17. J. Bartelt *et al.* (CLEO), *Phys. Rev. Lett.* **71** (1993) 4111.
 18. J. P. Alexander *et al.* (CLEO), *Phys. Rev. Lett.* **77** (1996) 5000.
 19. A. J. Buras, “Theoretical Review of B-physics,” in *BEAUTY '95* ed. N.

- Harnew and P. E. Schlein, *Nucl. Instrum. Methods* **A368**, 1 (1995).
20. Private communication from A. Buras.
 21. J.L. Rosner, Preprint EFI-98-45 hep-ph/9809545, to appear in the Proceedings of the 16th Int. Symp. on Lattice Field Theory, Boulder, Colorado, July 1998.
 22. M. Acciarri *et al.* (L3 Collaboration), *Phys. Lett. B* **396**, 327 (1997).
 23. A. Sokolov and G.C. Zucchelli (DELPHI), XXIX Int. Conf. on High Energy Physics, Vancouver, Canada, July 1998, ICHEP98 242 (1998); ALEPH, Int. Conf on HEP, Warsaw PA10-019 (1996); M. Artuso *et al.* (CLEO), *Phys. Rev. Lett.* **75**, 785 (1985).
 24. C. Caso *et al.*, *The European Physics Journal*, **C3** 1, 1998.
 25. C. Bernard, "Lattice Calculations of Decay Constants," in proceedings of 7th Int. Symp on Heavy Flavor Physics, Santa Barbara (1997).
 26. D. Acosta *et al.*, *Phys. Rev.* **D49**, 5690 (1994).
 27. S. Aoki *et al.*, *Progress of Theoretical Physics* **89**, 131 (1993). The WA75 value was based on the 1992 PDG value of $\mathcal{B}(D_s^+ \rightarrow K^+ K^- \pi^+) = (3.9 \pm 0.4)\%$ and $\mathcal{B}(D^o \rightarrow \mu \nu X) = (8.8 \pm 2.5)\%$. We scale the WA75 result using PDG ²⁴ values of $\mathcal{B}(D_s^+ \rightarrow K^+ K^- \pi^+) = (4.4 \pm 1.2)\%$ and $\mathcal{B}(D^o \rightarrow e \nu X) = (6.75 \pm 0.29)\%$ which we use for $\mathcal{B}(D^o \rightarrow \mu \nu X)$, after reducing the value by 3% to account for the smaller muon phase space.
 28. J. Z. Bai *et al.*, *Phys. Rev. Lett.* **74**, 4599 (1995).
 29. K. Kodama *et al.*, *Phys. Lett.* **B382** 299 (1996). The published result normalizes to $\mathcal{B}(D_s \rightarrow \phi \mu \nu) = (1.88 \pm 0.29)\%$, while the new PDG value is $(2.0 \pm 0.5)\%$.²⁴
 30. M. Chadha *et al.* (CLEO) *Phys. Rev. D* **58**, 032002-1 (1998).
 31. M. Bander, D. Silverman and A. Soni, *Phys. Rev. Lett.* **43**, 242 (1979).
 32. M. S. Alam *et al.* (CLEO), *Phys. Rev. Lett.* **74**, 2885 (1995).
 33. R. Ammar *et al.* (CLEO), *Phys. Rev. Lett.* **71**, 674 (1993).
 34. S. Glenn *et al.* (CLEO), "Improved Measurement of $\mathcal{B}(b \rightarrow s \gamma)$," submitted to XXIX Int. Conf. on High Energy Physics, Vancouver, Canada, July 1998 paper ICHEP98 1011 (1998).
 35. B. Barate *et al.* (ALEPH), "A Measurement of the Inclusive $b \rightarrow s \gamma$, Branching Ratio," CERN-EP/98-044 (1998).
 36. A. Ali and C. Greub, *Phys. Lett. B* **259**, 182 (1991). The parameters for this fit are $\langle m_b \rangle = 4.88$ GeV and $P_F = 250$ MeV/c.
 37. A. Czarnecki and W. J. Marciano, "Electroweak Radiative Corrections to $b \rightarrow s \gamma$," submitted to XXIX Int. Conf. on High Energy Physics, Vancouver, Canada, July 1998 paper ICHEP98 714 (1998); *ibid Phys. Rev. Lett.* **81**, 277 (1998); see also M. Neubert, "Theoretical Status of $b \rightarrow X_s \gamma$ Decays," hep-ph/9809377 (1998); A. Ali, "Theory of

- Rare B Decays,” hep-ph/9709507 DESY 97-192 (1997); N. G. Deshpande, “Theory of Penguins in B Decays,” in *B Decays Revised 2nd Edition*, ed. by S. Stone, World Scientific, Singapore, (1994).
38. J. L. Hewett, “ B Physics Beyond the Standard Model,” hep-ph/9803370 (1998).
39. S. Abachi *et al.* (D0), *Phys. Rev. D* **56**, 6742 (1997); F. Abe *et al.* (CDF), *Phys. Rev. Lett.* **78**, 4536 (1997).